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Flood Routing Model for Water Resources Optimization Models based on a Network Flow

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I. Introduction

Real-time operations of multireservoir models should contain a flow routing procedure to predict the impacts of the observed and/or predicted inflows hydrographs on the downstream parts of the river system. Solving separately the hydraulic and operational constraints is only possible when the water resources management model is based on an evolutionary algorithm.

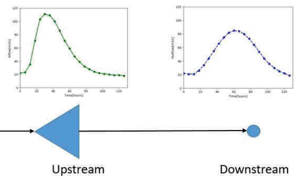

Figure 1: Flood routing

Conceptual models for channel routing like Muskingum model can be imbedded within the mathematical formulation of the optimization algorithm when it is linear. Nevertheless, no channel routing model has been developed for algorithms based on network flow approach, whereas they are commonly used to manage operations of multi-reservoir. The purpose of this work is to propose a special network structure which allows the consideration of river routing. The routing model is considered as a network flow and the parameters are calibrated using a genetic algorithm. Simplicity and accuracy are the main reasons for this choice, which are relevant characteristics to be adopted in optimization models. The flood routing model is validated on the Wilson event, and the results obtained are compared to the Muskingum's model results. A real example application on a reach of 40 km in the south west of France provided excellent results.

II. Objectives

1. **Developing a conceptual flood routing model based on a network flow approach.**
2. **Improving water resources optimization model by taking flood routing into account.**
3. **Validating the developed model on a real river which would improve its management.**

III. Residual Storage Model

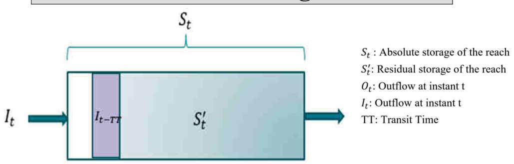

Figure 2: Residual Storage Model

All reservoir routing model developed consider that the outflow is a function of the absolute storage of the reach, whereas inflows during immediate moments have a negligible impact on the outflow. Let's define the Residual Storage of a reach as the portion of the absolute reach storage that impacts the outflow significantly. The Residual Storage Model (RSM) developed herein considers that outflow at time *t* is a linear function of the sum of the residual storage and inflow at time *t-TT*:

$$O_t = (1-\alpha)(S'_t + I_{t-TT})$$

The proportionality coefficient α physically represents the proportion of the residual storage that stays in the reach.

IV. Motivation of this work

The optimization problem for the operation of multi-reservoir systems under flooding conditions can be stated as follows:

$$Minimize\ z = f(h, Q)$$

Subject to:

$(a)\ Hydraulic\ constraints: g(h, Q) = 0$

$(b)\ Bounds\ on\ discharges:\ \underline{Q} \le Q \le \overline{Q}$

$(c)\ Bounds\ on\ elevations: \underline{h} \le h \le \overline{h}$

Hydraulic approach

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(\beta Q^2/A\right)}{\partial x} + gA\left(\frac{\partial h}{\partial x} + S_f + S_e\right) - \beta q V_x = 0$$

Conceptual approach

$$\frac{dS}{dt} = I - O$$

$$S = f\left(I, \frac{dI}{dt}, \ldots, O, \frac{dO}{dt}, \ldots\right)$$

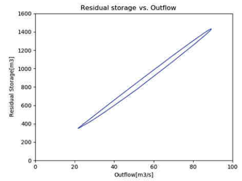

Figure 3: Residual Storage Vs. Outflow (RSM Model)

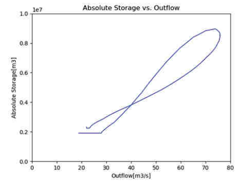

Figure 4: Absolute Storage Vs. Outflow (Muskingum Model)

Comparison on the Wilson Event

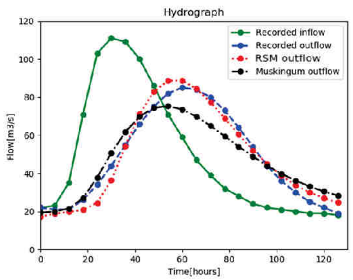

Figure 5: Recorded and modeled outflow for Wilson event

V. Network Flow Model Formulation

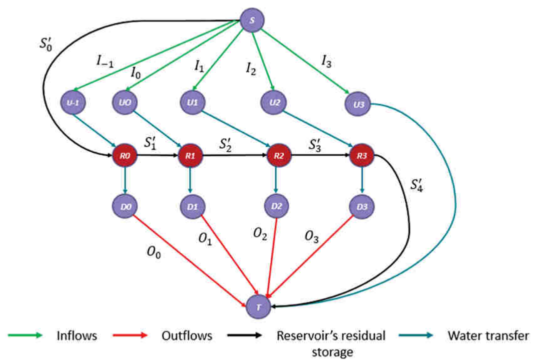

Figure 6: Network model corresponding to a reach, with TT=1 and Horizon=4

The Residual Storage Model can be represented as a network in order to integrate the hydraulic constraints in a water management problem based on a network representation. Let *G=(V; E)* be a directed single source network, with node set *V* and arc set *E*. Let *S* and *T* be the source and the sink nodes of the network, respectively. The source and sink nodes are fictive nodes that supply the upstream of the system and collect the downstream flows. Nodes stand for points of convergence or diversion and for reservoirs. Arcs represent water transfer. Flows are dynamic and do not travel instantaneously through the network. Hence, nodes are duplicated at each time step over the duration of the simulation, and the transit times and flows are implicit in arcs linking those copies. A reservoir node is set between every upstream and downstream node to model the reach's flood routing. The outgoing flow from an upstream node at time *t* gets connected to the reservoir node at time *t+TT* where *TT* corresponds to the reach's transfer time. The reservoir node divides the incoming flow into 2 flows: a flow representing the residual storage remaining in the reservoir and a flow representing the volume released from the reservoir at time *t*.

Before using the flood routing model, the model's parameters should be calibrated. The simulated outflows should approximate the measured downstream flows. The parameters of the model are the reach transit time, the distribution coefficient, and the initial residual storage. The optimization method used in this study to calibrate the model is the genetic algorithm (GA) solver in MS Excel coupled with a network model. A genetic algorithm is used here because of its handling of complex objective functions, an advantage it has over traditional optimization algorithms.

VI. Application

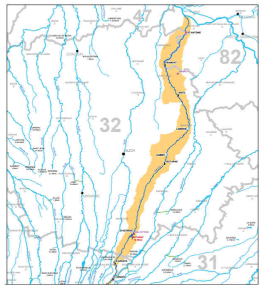

Figure 7: Arrats' Watershed

Figure 8: Watershed localization

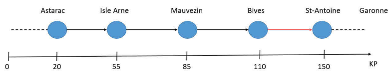

Figure 9: Synoptic of the Arrats' river

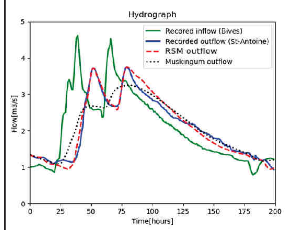

Figure 10: Results of the calibration

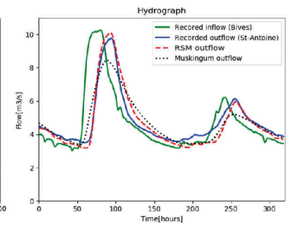

Figure 11: Results of the simulation

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